FRACTURE STRENGTH AND FRACTURE MODE OF RESIN ROOT ANALOGS RESTORED WITH VARIOUS POST AND CORE MATERIALS

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Statement of Problem. Endodontically treated teeth frequently required posts and cores to provide retention and resistance form for crowns. In spite of excellent mechanical properties of metal post and core, its metallic color can be detected through all ceramic restorations occasionally. To solve esthetic problems of metal post and core zirconia post system has been introduced recently.
Purpose. The purpose of this study was to examine the fracture strength and mode of resin root analogs restored with zirconia, gold and titanium posts with resin, ceramic and metal cores after cementation with metal crowns.
Materials and methods. To avoid the morphological variations of natural teeth, 40 root analogs were fabricated with composite resin. Forty resin root analogs were randomly assigned to four groups according to post and core materials:
Group A: cast gold post and core and complete cast crowns, as control.
Group B: titanium posts (Parapost, Coltent / Whaledent Inc., NJ, USA) and composite resin cores.
Group C: zirconia posts (Cosmopost, Ivoclar AG, Schaan / Liechtenstein) and composite resin cores
Group D: zirconia posts and heat-pressed ceramic cores (IPS Empress Cosmo Ingots, Ivoclar AG)
After thermocycling (5℃ ~ 55℃, 30 sec.), cyclic loading was applied at 3mm below the incisal edge on the palatal surfaces at an angle of 135 degree to the long axis (2Hz, 50N, 50000cycles).
Fracture strength was measured by universal testing machine (Instron, High Wycombe, UK) and fracture pattern of restored resin root analogs was also evaluated.
Results and conclusion. Within the limitations of this study following results were drawn.
1. Resin root analogs restored with zirconia posts and composite resins demonstrated lowest fracture strength among tested groups.
2. There was no significant difference in the fracture strength between zirconia posts and heat pressed glass ceramic cores and cast gold posts and cores
3. The fracture strength of resin root analogs restored with titanium posts and composite resin cores was lower than that of gold posts and cores.
4. The deep oblique fracture lines were dominantly observed in root analogs restored with cast gold post and core and zirconia post and heat-pressed ceramic core groups.

Key Words
fracture strength, post and core, resin root analog, zirconia, cyclic loading

In most teeth with little sound dentin, they need post and core, not for reinforcing teeth but for retention and resistance form of prepared teeth.[1] The use of cast gold post and core has long been advocated for the rehabilitation of endodontically treated tooth.[2] However, in the restoration of all ceramic crown, the tooth may lead to compromised esthetics because of the semi-translucence of ceramics and the grayish metal substructure of the underlying post and core. Depending on the thickness and the opacity of the cementing medium and the all-ceramic restoration, the metal post and core can be displayed through or at least decrease the depth of translucency of the restoration.

To overcome these esthetic problems, various techniques have been proposed. Such as the application of porcelain to the metal core[3,4], the use of opacious luting cement[5], or resin veneering to the cast core[6] gives a relatively intense and opaque appearance to the restoration. However, the shade of metal post could be seen through free gingival area. Therefore, all ceramic post and core was proposed as a substitute for metal post and core to improve esthetics. Until early 1990s, posts composed of ceramic materials could not be used because of their insufficient mechanical properties and the complicated multistep clinical protocol.[7,8]

In 1993, Luthy et al. introduced post made of tetragonal zirconia polycrystals (ZrO_2-TZP) that have a high flexural strength (1400Mpa) and an optimal esthetic appearance.[9] Prefabricated zirconium oxide intraradicular post (Cosmopost, Ivoclar AG, Schaan / Liechtenstein) is partially stabilized by the addition of yttrium oxide to form a tetragonal zirconia polycrystals ceramic.[10] Yttrium oxide also provides the material with microstructure grains of 0.4μm that achieve a surface roughness as fine as 0.008 μm. In addition to good physical properties, this zirconium oxide is stable at human body temperature, radiopaque, and does not promote adverse reactions to biological tissues.[11]

In 1997, a ceramic core material (IPS Empress Cosmo Ingot, Ivoclar AG) that can be heat pressed directly onto zirconia post was introduced. It is based on the well-known IPS Empress system (Ivoclar). Through heat pressing, zirconia post and glass core material can be fused into a solid post and core restoration.[12]

The preparation design of pulpless teeth is another critical consideration in the restoration of endodontically treated teeth. Since the bulk of the remaining tooth provides resistance to fracture, it is recommended to save as much of the natural tooth as possible.[13] In addition, the marginal area of a complete crown, which is extended onto the tooth structure beyond these core materials, creates a ferrule. The ferrule is defined as a metal band or ring used to fit the root or crown of a tooth.[14] This ferrule or encircling band of cast metal around the coronal surface of the tooth has been suggested to advance the integrity of the endodontically treated tooth. Sorenson and Engelman reported the importance of maintaining "parallel walls of dentin coronal to the shoulder of the preparation" to enhance the tooth's strength.[15] But, sometimes dentists are faced with the teeth having no coronal dentin, and ferrule effect, which reinforces teeth restored with posts and cores, cannot be achieved. There are few reports about the resistance to fracture of the retained roots restored with all ceramic post and core systems.

The purpose of this study was to evaluate the fracture strength and the fracture mode of resin root analogs simulating retained root, which were restored with zirconia posts with composite or heat pressed ceramic core in comparison with conventional post and core systems.

MATERIALS AND METHODS

For the studying the fracture strength and fracture mode, it is difficult to use the roots of natural teeth because there are many variables, such as crown length, shape of teeth, cross-sectional area of root, root length and surface integrity. In addition, crack may occur during the extraction. So, the utilization of an analog is an attractive substitute to extracted teeth. Their employ eliminates geometric differences and variations of structural integrity. Milot and Stein used these analogs in their investigation of restored decoronated roots.[16]

Published average dimensions for human teeth were used to select an representative extracted maxillary central incisor.[17] A transparent epoxy resin (ITW Devcon, IL, USA) was used to fabricate two-piece mold of the selected tooth. This transparent mold was then filled with microglass filled composite resin (Charisma, Heraus Kulzer GmBH & Co., KG, Germany) to replicate average sized tooth. This material was selected because its compressive strength and modulus of elasticity are similar to those of human dentin.[18-21]

Curing light (Curing Light XL3000, 3M Dental Products, MN, USA) was directed for 40 seconds each at two locations on the mesial aspect of the mold and then on the distal aspect. After light curing and removal from the mold, coronal structure of this resin analog was removed to simulate retained root of 13mm length. Replicated resin analog was prepared to make inner shoulder (depth 2mm, diameter 3mm). Then, similar second transparent mold was fabricated to duplicate decoronated resin analog. After the mold was filled with the same composite resin described above, packed and clamped, curing light initiated polymerization through the transparent mold case. After removal from the transparent mold, resin analogs were in light exposure for 40 seconds repeatedly to the surfaces of each specimen to make sure high degree of polymerization. Through duplicating and light curing procedure described above, 40 resin analogs were fabricated.

Fabricated resin analogs were restored with four post and core systems, and outer crowns were fabricated (Fig. 1).

Because resin analog had no root canal, diamond bur (No 4, SS White Burs Inc., NJ, USA) in high-speed handpiece (Tradition L, Dentsply Midwest, IL, USA) was used to simulate root canals and 5mm from the root apex was remained intact to imitate apical seal. Subsequently root canals were enlarged using a 1.7mm post drill (Cosmopost drill kit, Ivoclar AG) to receive posts except group B. In the group B, root canals were prepared using 1.75mm Parapost drill (Parapost, Coltene / Whaledent Inc., NJ, USA).

In the group A, Parapost burnout pattern (Coltene / Whaledent) added by inlay wax (Blue Inlay Wax, Yooshin, Korea) to fit prepared root canal was seated, and core pattern was waxed-up. Then, post and core wax patterns were invested (Christobalite Inlay investment, Whip-mix, Kentucky, USA), and cast in type Ⅳ gold alloy (Hee Sung Engelhard Corp., Seoul, Korea). The cast gold posts and cores were sandblasted with aluminum oxide, and primed (Alloy Primer, Kuraray, Osaka, Japan).

In the group B, prefabricated titanium posts (Coltene / Whaledent) were sandblasted, and in the group C, 1.7mm Cosmoposts were cleansed with 37% phosphoric acid etchant (Scotchbond, 3M Dental Products), rinsed and dried. In the group D, Cosmoposts were fitted and core patterns were built-up with inlay wax. The post with core pattern was subsequently invested with special investment (IPS Empress Investment, Ivoclar). After burnout and preheating procedures, cores were heat pressed with a glass ceramic (IPS Empress Cosmo Ingot, Ivoclar AG) at 900℃ and 5 bars. All resin analogs were prepared like composite resin restorations, e.g. etching (K Etchant Gel, Kuraray), cleansing, drying and application of primer (Clearfil Porcelain Bond Activator, Kuraray), all posts were cemented using autopolymerizing resin cement (Panavia F, Kuraray). In the group B and C, composite resin (Z100 restorative, 3M Dental Products) was built up to fabricate core.

Using polycarbonate crown fitted to resin analog, the crown patterns were waxed-up, invested (GC Fujivest Ⅱ, GC Europe, Leuven, Belgium), and cast in a non-precious alloy (Vera-Bond, Aalba Dent Inc., CA, USA, Fig. 2). All crowns were cemented with modified glass ionomer cement (Fuji-Plus, GC Corp., Tokyo, Japan) following the procedure recommended by the manufacturer.

Restored resin analogs were allowed to bench set for 24 hours, after which each root received a band of utility wax. The apical border of the wax band was placed 3mm from the crown margin to simulate biologic width. Then, the aluminum foil of 0.2～0.3mm thickness wrapped root portion below the wax margin. After resin analog was set up at an angle of 135 degrees to the long axis in the mold with parallelometer, mixed PMMA (Duralay, Reliance Dental Mfg.) was poured in. The embedded specimens were allowed to polymerize at room temperature for 24 hours, then the space between resin analog and bone simulating PMMA created by aluminum foil was filled with silicone impression material (Examix, GC) to simulate periodontal membrane. All specimens were allowed to thermocycle between 5℃ and 55℃ for 1000 cycles, with 30 seconds of soaking at each temperature and no intermediate pause (Fig. 3). After thermocycling, all resin analogs were exposed to 50000 cycles with a load of 50N at a frequency of 2Hz, by chewing simulator (MTS 858

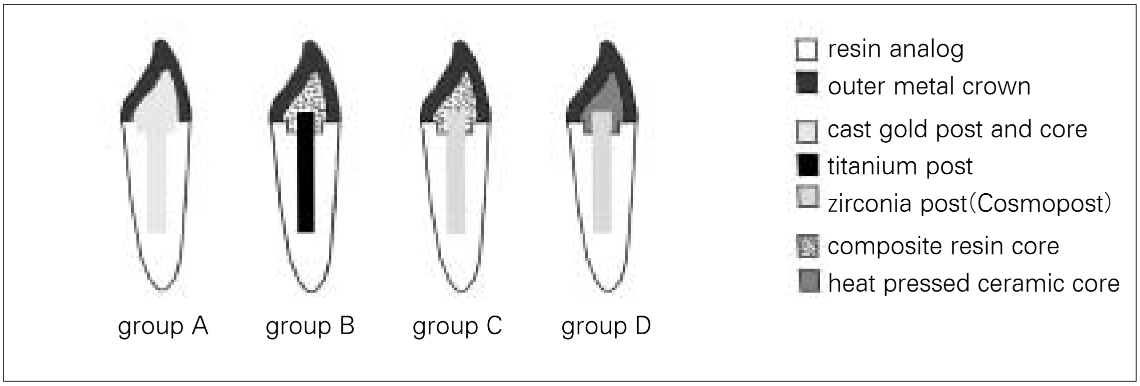

Fig. 1. Schematic drawings of each restored groups. Group **A**: restored with cast gold posts and cores, as control. Group **B**: restored with titanium posts and resin cores. Group **C**: restored with zirconia posts and resin cores. Group **D**: restored with zirconia posts and heat pressed ceramic cores.

Fig. 2. Metal crowns and resin analogs with posts and cores.

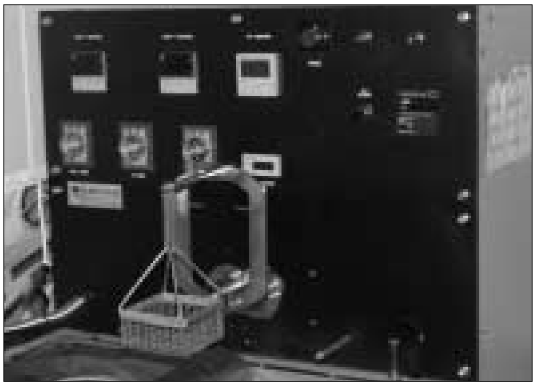

Fig. 3. Thermocycling machine.

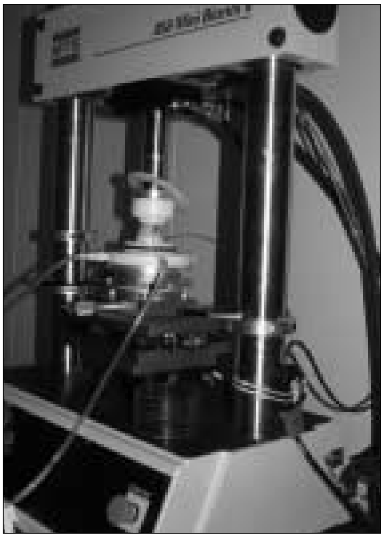

Fig. 4. Chewing simulator.

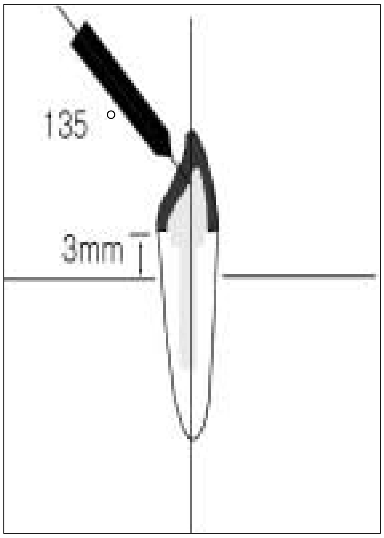

Fig. 5. loading pattern.

Mini Bionix Ⅱ system, MTS systems corp., Fig. 4).

None of the specimens was fractured during cyclic loading. Each specimen was loaded to fracture in a universal testing machine (Instron, High Wycombe, UK) with a cross head speed of 2mm / min, and fracture loads and fracture patterns were recorded. The chewing simulator and universal testing machine loaded specimens at 3mm below the incisal edge on the palatal surfaces at an angle of 135° to the long axis of the analogs (Fig. 5).

From all recorded datas, means and standard deviations of each group were calculated, and statistical analysis was performed using the Mann-Whitney U-test. The results with P values < 0.05 are considered statistically significant.

RESULTS

1. Fracture strength

Table Ⅰ shows the fracture strength of all specimens, mean value, and standard deviation of each group. The mean and standard deviation of each group are depicted in Fig. 6 and statistical analysis in Table Ⅱ.

Table Ⅰ. Fracture strength of each specimens, group A: cast gold post and core, group B: titanium post and composite resin core, group C: zirconia post and composite resin core, and group D: zirconia post and heat pressed glass ceramic core

Group	Fracture strength (unit:N)			
	A	B	C	D
1	503.3	342.1	297.4	430.5
2	449.5	388.5	298.4	584.4
3	385.9	373.9	484.1	378.2
4	490.0	453.8	403.2	558.3
5	407.6	417.0	422.0	547.0
6	487.5	444.1	357.9	437.1
7	378.3	398.4	353.4	379.7
8	523.1	389.3	304.7	389.4
9	498.4	378.3	344.7	405.2
10	478.4	388.0	354.8	478.3
Mean	460.2	397.3	362.1	458.8
S.D.	52.0	33.3	59.8	78.6

The resin analog restored with cast gold post and core tolerated significantly more loading than that with the zirconia post and composite resin

Table Ⅱ. Statistical analysis of fracture strength

	Au/Au	Ti/CR	Z/CR	Z/GC
Au/Au		P=0.015*	P=0.002*	P=0.796
Ti/CR		-	P=0.123	P=0.075
Z/CR			-	P=0.005*

Mann-Whitney U-test, P<0.05 (* significant)

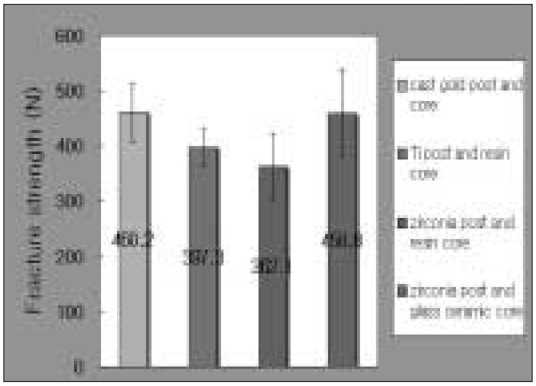

Fig. 6. Fracture strength of the specimens

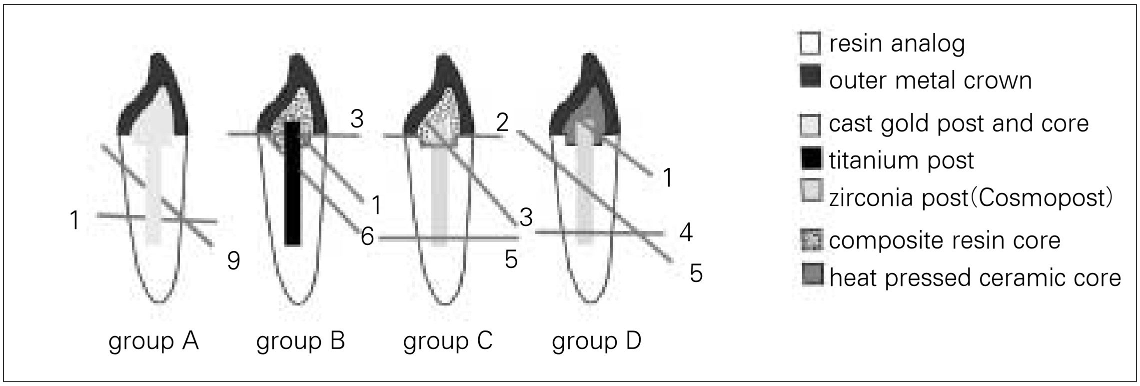

Fig. 7. Fracture patterns in the four groups of specimens. Thick lines indicate the fractures of the resin analogs, and thin lines indicate the fracture of posts and cores.

core. The specimens with zirconia post and heat-pressed glass ceramic core are more resistant to fracture than that with zirconia post and composite resin core, and have similar fracture strength to that with cast gold post and core. In the case of the specimens with titanium post and composite resin core, its mean fracture strength is less than that with zirconia post and heat-pressed glass ceramic core, but difference is not statistically significant. In systems using resin core, resin analog in the group B has higher mean fracture strength than specimens in the group C, but it is not statistically important.

2. Fracture patterns

In the control group, oblique root fracture occurred except one specimen. The group with titanium posts showed six oblique fractures and four core fractures, and titanium posts were intact. The teeth restored with zirconia posts and composite resin cores demonstrated that five horizontal root fractures, three core fractures, and two interfacial failures between core and tooth. Five teeth of group D were fractured in oblique pattern, four were horizontally, and one was failed at ceramic core. All zirconia posts in the group C and D were fractured in combination with the fracture pattern described above (Fig. 7).

DISCUSSION

The choice of resin analogs to simulate teeth was made to eliminate the variables of morphology, age, and both pre-extraction and post-extraction mechanical flaws that may occur during the extraction of teeth. Though the advantages of resin analogs to preclude such variations are obvious, it is not certain that the findings of this study are clinically predictive. It must be acknowledged that composite resin differs mechanically from tooth in at least two aspects. The ultimate tensile strength of composite resin used in this study is lower than that of dentin[18,20], although compressive strength and modulus of elasticity are similar. In addition, the analog material is relatively isotropic, whereas dentin is anisotropic due to its tubular structure. Although these differences existed, it was not intended at quantifying the specific values for which clinical failure of natural teeth might occur, but intended at comparing the relative fracture strength.

Another consideration of the resin analog relates to chemical bonding. Gegauff, who studied differences of load failure of posts and cores between crown lengthened and ferrule placed teeth with resin analog, used zinc phosphate cement as luting agent.[22] In this study, resin analogs and zirconia posts were cemented with resin cement (Panavia F), because it is recommended to use resin cement in cementation of zirconia post to tooth. Chemical bonding of resin analogs with each post may be problematic because the bonding mode differs from that of natural teeth. This investigation was not for quantifying the specific values of fracture strength, and all specimens were prepared identically. Therefore in the relative comparison of fracture strength of ceramic post and metallic post, the difference of the bonding mode between resin analogs and natural teeth was not significant.

There are a few reports with the teeth restored with zirconia post system. Butz et al. and Strub et al. investigated the fracture strength of the 2mm coronal dentin remaining teeth restored with zirconia post system.[23,24] It is well known that ferrule strengthen the teeth restored with posts and cores.[25,15] The retained root restored with post and core to retain crown was failed at lower load than the teeth with coronal dentin due to ferrule effects. In this experiment, retained root restored with zirconia post and composite resin core had lower fracture strength than those with cast gold post and core and zirconia post with heat-pressed core. It coincides with the results of the previous study.[23] The direct technique that uses a zirconia post with composite resin core can be employed when a minimum of one third of the clinical crown is present.[26] As all composite structures, those made with zirconia posts can experience a shrinkage gap between the tooth structure and the core material that may result in microleakage beneath the crown restoration.[27] In addition, recent study has demonstrated that less than ideal bond strength appears to exist between the zirconia post and composite material.[28] In the group with titanium post and composite resin core the fracture strength was lower than cast gold post and core group. But, Butz et al. reported that the tooth restored with titanium post and composite resin core had similar fracture strength to the tooth with cast gold post and core.[23] The results of the previous study ,which is different from that of this study, may be due to the existence of remaining coronal dentin. Because microleakage of composite resin core, which was critical to retained roots, might occur during thermocycling and cyclic loading, tooth could be easily fractured. It was also proved by the results of this study that the fracture of specimens restored with titanium posts and composite resin cores occurred more frequently at the core portion than cast gold post and core group.

The heat-pressed ceramic has a coefficient of thermal expansion compatible with that of zirconia.[29] The zirconia post and glass ceramic core used in this study were made in same manufacturer, and its combination is optimal. Another report about heat-pressed ceramic core demonstrated that the tooth with heat-pressed ceramic core had lower resistance to fracture than that with the cast metal post and core, and explained that it was due to changes within the inner structure of the zirconia material during the heating process.[24] But zirconia post used in their study was made by another manufacturer (Cerapost, Brasseler, Lemgo, Germany). Thus, zirconia post, which was not designed for heat-pressing, might be a cause for lower resistance to fracture in their investigation.

Another important factor is the possibility of restoration in the event of a failure. Two frequent situations of the post and core failures were loosening of the post and tooth fracture.[30-32] Even though frequency of tooth fracture was lower than that of post loosening, fracture of the roots may lead to the worst situation, i.e. extraction. Deep oblique root fracture, that frequently occurred in the group A and D, usually leaves the tooth unrestorable, requiring extraction. On the contrary, a few analogs in the group B and C were fractured at the core and the interface with core and analog, and those can be reconstructed.

All resin analogs in this experiment were covered with base metal crowns. However, as mentioned above, the use of all ceramic crown system in the groups with zirconia posts would be clinical reality. If the study had been done with all ceramic crowns as a outer crowns, the results might have been different and more clinically reliable.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn:

1. Resin root analogs restored with zirconia posts and composite resins demonstrated lowest fracture strength among tested groups.
2. There was no significant difference in the fracture strength between zirconia posts and heat pressed glass ceramic cores and cast gold posts and cores
3. The fracture strength of resin root analogs restored with titanium posts and composite resin cores was lower than that of gold posts and cores.
4. The deep oblique fracture lines were dominantly observed in root analogs restored with cast gold post and core and zirconia post and heat-pressed ceramic core groups.

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